

Renewable energy: Progressing towards a net zero energy island, the case of Reunion Island

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ABSTRACT

For the last two decades, economic development in Reunion Island has led to major structural changes. The latter have been characterized by an increase in energy demand per person. This demand is mostly related to a high population growth (1.55% per year). Reunion currently has 833,000 inhabitants. The population will rise to 1 million in 2030. Like most ultraperipheral regions of the European Union, Reunion is heavily dependent on imported fossil fuels for its energy production. The total primary energy consumption amounted to 1352 ktep in 2009 and 87.1% is imported energy. The development of various renewable energies such as solar energy, biomass, ocean energy, etc. is thus of priority concern to aim to achieve energetic independence. Just like other French overseas territories, Reunion policies have widely invested in Renewable Energy Sources (RES) since 2000. This paper aims at presenting the current status, the major achievements of policies and the future objectives in the deployment of renewable energy programmes. The perspective of a net zero energy island versus the pressure of the population is analysed. The barriers to penetration of RES in a small-scale territory are also discussed.

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1. Introduction

Reunion Island is a French overseas territory and an ultraperipheral region of Europe. It is the only European region in the southern hemisphere. It lies at 21°06' South and 55°32' East, which locates it in the North of the tropic of Capricorn. It has a total area of 2512 km² with an estimated population of 833,000 in 2010 [1]. As it is a small territory, the island's development is closely related to its geographical situation, energy production and municipal solid waste management [2,3]. During the Amsterdam summit about climate change, the heads of states recognized in their declaration on island regions that "island regions suffer from structural handicaps linked to their insular status, the permanence of which impairs their economic and social development", [4]. The commission for islands considered that implementing experimental practices with regard to governance in its islands was an interesting and promising objective [5]. The case of Reunion Island is particularly specific as it is far away from any European or continental territories; it is thus impossible to link the island to any energy production network. Aware of all these handicaps, Reunion turned to the definition of a policy of energy management and the use of RES as a sustainable alternative to partly produce its energy. Reunion Island comes as an interesting experimental laboratory for testing and developing new technologies due to its insular nature, tropical humid condition and small-scale territory. The recent upward trend in oil prices indicates that the global oil market has entered a phase of depletion caused by the contradictory effects of accelerating growth in global oil consumption due to the rise of emerging countries and the freeze of supply, which led to a slowdown in oil production. In its latest World Economic Outlook, the International Monetary Fund promotes the development of alternative energy sources, [6]. Energy planning has to be considered in the context of climate change negotiations. The International Energy Agency (IEA) reports in its "World Energy Outlook" that energy-related CO₂ emissions will decline from 85% in 2008 to 70% in 2020 [7]. This projection scenario is defined under the Copenhagen Accord which sets a goal to take action to restrict global warming to 2 °C. In France, this Agreement results in the intended stabilization of the gas emissions in 2012 (under Kyoto protocol), and the goal for 2020 is to reduce greenhouse gases up to 20% compared to their 1990 level. As well as considering the environmental impact, the economical aspect is of fundamental importance. Oil products and coal prices, respectively, surged over 100 USD per barrel and 80 USD per ton. Global energy price increases could have a deep impact on the weak economic fabric of the island. Renewable energy technologies consequently appear to be the most attractive solution to move from a system based on fossil fuel to a 100% renewable energy-system. As Reunion Island has abundant renewable energy resources, at the end of the 1990s the goal of self-sufficiency was defined on the 2030 horizon. This date corresponds to the end of the projected demographic transition; the population should stabilize at

1 million people. Much research has investigated the concept of energy independence at the 2030–2050 period. The results have shown that it is feasible but have also underlined the fact that achieving 100% RES still remains a challenge [8–12]. From this perspective it is necessary to investigate a large number of alternative RES. The term of "Zero Energy Island" firstly introduced by Bagci, [13], is similar to the NZEB (Net Zero Energy Building), a term extended to islands. This paper provides an overview of the present energy status and policy, before then discussing the self-sufficiency outlook of Reunion at 2030.

2. Energy situation and consumption

Reunion is a densely populated island with 331 people/km² (12th French *département* in terms of density). Rapid economic growth of 5% over the last two decades correlates with comparable growth in energy demand. Total energy demand has increased from 1.025 ktep in 2000 to 1.352 in 2009 (Table 1). Energy sufficiency fluctuates from 84.7% to 87.7%.

As shown in (Table 1), Reunion is highly dependent on coal and fuel oil for several energy sectors. The analysis of the exploitation of fossil resources has highlighted two major sectors in final energy consumption: transport (49.7%/585.7 ktep) and electricity (44.5%/527.7 ktep). In 2009, electricity production was 2618.2 GWh of which 67.5% from primary fossil energy (petroleum and coal) and 32.5% from RES. It was the first time since 2005 that the portion of RES production was lower than 32.5%. It can be noted that the average growth rate of electricity production was approximately 5.3% per year between 2000 and 2005. The growth rate decreased to 3.6% per year from 2006 to 2009. This inflexion was the result of a demand side management programme defined since 2000 in Reunion. The average electricity consumption is 1.29 MWh per person versus 2.37 MWh per person in France. However, no immediate comparison is possible as there is no need for heating during the winter season in Reunion.

As shown in Fig. 1, the portion of renewable energy sources in PEC has decreased since 2003. However, the PEC from renewable energy stabilized at 166 ktep during the 2008–2009 period. However, in parallel, consumption from fossil resources has raised by 5.9% (from 1120.5 to 1186.2 ktep), which explains a lower self-efficiency rate in 2009. Thus, it can be concluded that even if the share of RES has gradually increased in the last 10 years, fossil fuel energy consumption still remains high.

Regarding load curve, the peak loads occur in the morning (after 7 a.m.) and in the evening (after 6 p.m.) for both seasons (cf. Fig. 2).

In the morning the peak load is essentially due to air-conditioning (AC) systems. It can be observed that the load does not decrease much during the day in the summer period. In winter, the two peaks appear clearly; we can also notice that the evening peak is higher than the morning one. The difference between the

Table 1
Energy supply according to resource.

Item	2000		2005		2008		2009	
	ktep	%	ktep	%	ktep	%	ktep	%
Imported resources								
Petrol	140.4	13.7	137.1	11.8	120.4	9.4	119.7	8.9
Fuel oil	490.5	47.9	540.3	46.6	554.3	43.0	638.2	47.2
Butane	30.9	3.0	28.6	2.5	26.1	2.0	25.5	1.9
Coal	207.1	20.2	303.4	26.2	419.7	32.6	402.8	29.8
Local resources								
Sugarcane bagasse	104.5	10.2	94.6	8.2	94.4	7.3	99.4	7.4
Hydropower	48.1	4.7	43.9	3.8	54.4	4.2	45.7	3
Thermal solar	2.2	0.2	8.5	0.7	13.2	1.0	14.4	1.1
Waste oil	1.9	0.2	2	0.2	1.8	0.1	1.6	0.1
Other RES			0.05	–	2.2	0.2	4.8	0.4

Table 2
CO₂ emissions produced by combustion of fossil resources, [14].

	tCO ₂ /capita
World	4.39
OECD	10.61
France	5.74
Réunion	4.87
China	4.92

summer and winter load curves can be explained by the fact AC is not used during winter. Electricity production represents 49.1% of CO₂ emissions in Reunion.

In keeping with the wider global situation, energy-related CO₂ emissions represent the greatest part of overall Reunion greenhouse gas emissions. At the moment, 94.6% of CO₂ emissions, corresponding to 3,980,867 t, are produced by the energy sector. The average emission ratio per kWh is 820 g CO₂. In France, this rate is 84 g CO₂/kWh due to nuclear energy sources. CO₂ emissions have increased to 0.5% since 2008.

According to Table 2, CO₂ emissions in Reunion are lower than in France. This value can be explained by the economical situation of Reunion Island. However, it can be observed that, unlike France, the ratio of CO₂ increased from 4 tCO₂/pop. in 2004 to 4.87 tCO₂/pop. in 2010. In the same period, France had a drop of 1.86 tCO₂/pop. (from 7.6 to 5.74). What is particularly alarming is that Reunion

is undergoing demographic and economic transition. Thus, in all likelihood, the rise of CO₂ emissions will continue if nothing is done to implement the sustainable development of RES technologies to meet future demand (Table 3).

Through a review of the energy status of Reunion, it can be concluded that the development of renewable energy technologies is becoming crucial in the objective of sustainable economic development. The penetration of RES is increasing at a slower rate than demography, which has induced a small fall in self-efficiency rate over the last 4 years. Reunion's energy self-sufficiency is expected to increase from 12% in 2009 to 50% in 2020. The following sections present a review of present RES utilization and discuss the potential of renewable energy development in Reunion.

3. Renewable energy deployment in Reunion

With the aim of approaching energy autonomy by 2030, Reunion has widely invested in RES over the last 20 years. The most developed renewable energy in terms of power is hydropower. The 1990s saw the development of domestic solar water heating (SWH). Reunion is blessed with many types of RES such as solar, wind, geothermal, sea energy and hydropower; this is why it is determined to become an example of an Energy Self-sufficient Island. The availability of RES has made Reunion into a small-scale laboratory experimenting renewable technologies for France.

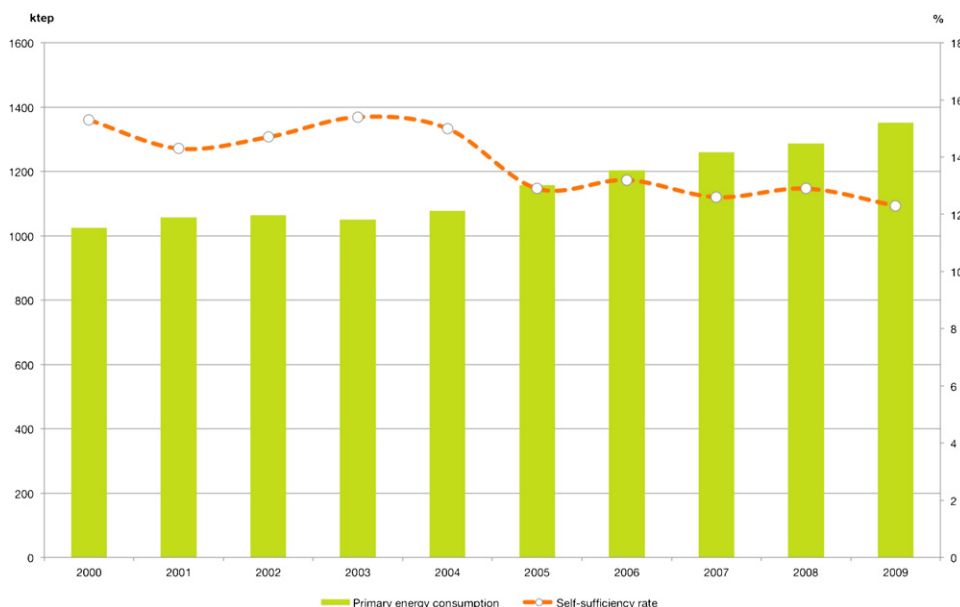
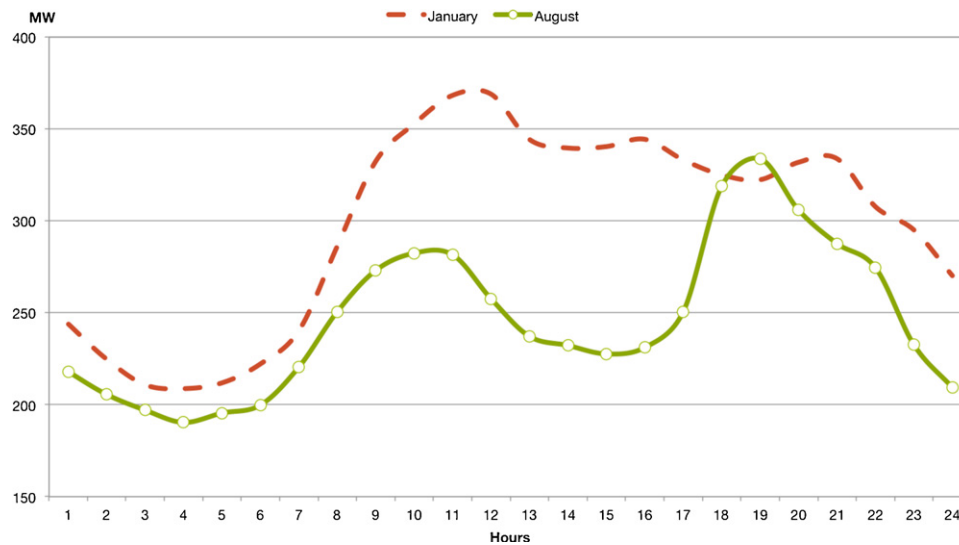


Fig. 1. Year-wise evolution of primary energy consumption (PEC) and self-sufficiency rate (%).

Table 3

Electricity installed capacity and electrical production from biomass over 2000–2025 according to current energy policy scenario.

	Electricity installed capacity in 2000 (MW)	Electricity installed capacity in 2010 (MW)	Electricity installed capacity in 2025 (MW)
Bagasse	114	124	124
Biogas	0	5	8
Wood energy	0	21	21
Vinasse	0	13	13
Total	114	163	166

**Fig. 2.** Daily variation of electricity production in summer/winter months.

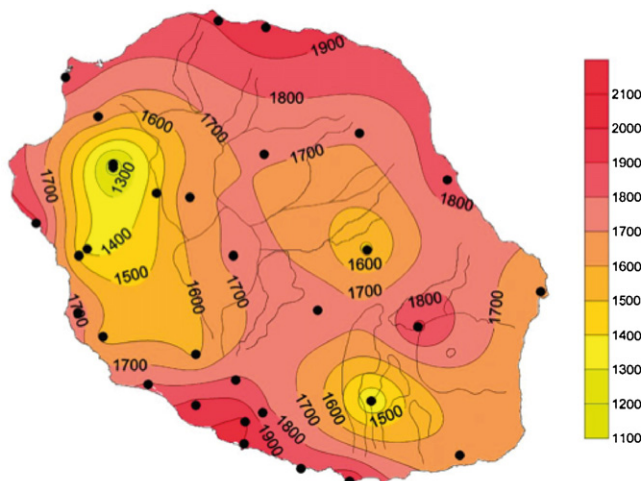
3.1. Solar energy

Due to its location, solar energy is an abundant energy resource in Reunion (cf. Fig. 3). Essentially most RES are indirect solar energy forms such as biomass, hydro, wind, ocean, etc. The availability of this resource makes the development of all solar technologies particularly interesting. Annual sunshine is in the range of 1400–2500 h and can reach the value of 2900 h, for an altitude lower than 400 m. Daily insolation is characterized by a strong evolution due to orographic cloud formations on the mountains. Thus, clear sky conditions can be observed in the morning rather than in the afternoon. The monthly daily radiation reaches more than

6.5 kWh/m² during the wet season in some parts of the coastal region (altitude <300 m). In term of direct solar energy use, the two main applications in Reunion are solar water heating (SWH) and photovoltaics (PV).

3.1.1. Solar thermal energy

The main use of solar thermal energy in Reunion is solar water heating (SWH). Since 2009, RTAA DOM¹ standards have required the promotion of renewable energy by SWH systems for all new dwellings on the island, [16]. SWH is used for the development of domestic hot water production use such as bathing, cooking or cleaning. While the use of SWH is now a success story, this has not always been the case. Indeed, in the early 1980s many SWH systems were installed. However, the lack of monitoring and maintenance rapidly reduced the number of facilities. Energy policy initiated in the mid 1990s has boosted this activity. At the end of 2009, 102,666 SWH systems (300 L equivalent) operated on the island. The total area of solar collectors installed reached 410,664 m², which corresponds to a thermal production of 154 GWh (cf. Fig. 4). Household SWH systems could save 1167.7 GWh of electricity per year. Concerning collective SWH (commercial and institutional buildings), 22,796 m² had been installed at the end of 2009, saving 13.7 GWh of electricity. In fact, there are more collective SWH systems installed, but available data only concern installations supported by interest subsidies and capital from governmental institutions. With 502.6 m²/1000 capita, Reunion is the leading French *département*, and holds third position in Europe, in terms of installed SWH. The mean value for France is currently 32 m²/1000 capita, whereas Cyprus, the leader in Europe, has a ratio of 671 m²/1000 capita.

**Fig. 3.** Global solar irradiance (kWh/m²) distribution in Reunion.[15].

¹ RTTA DOM: Specific thermal, acoustic and ventilation standards for French overseas *départements*.

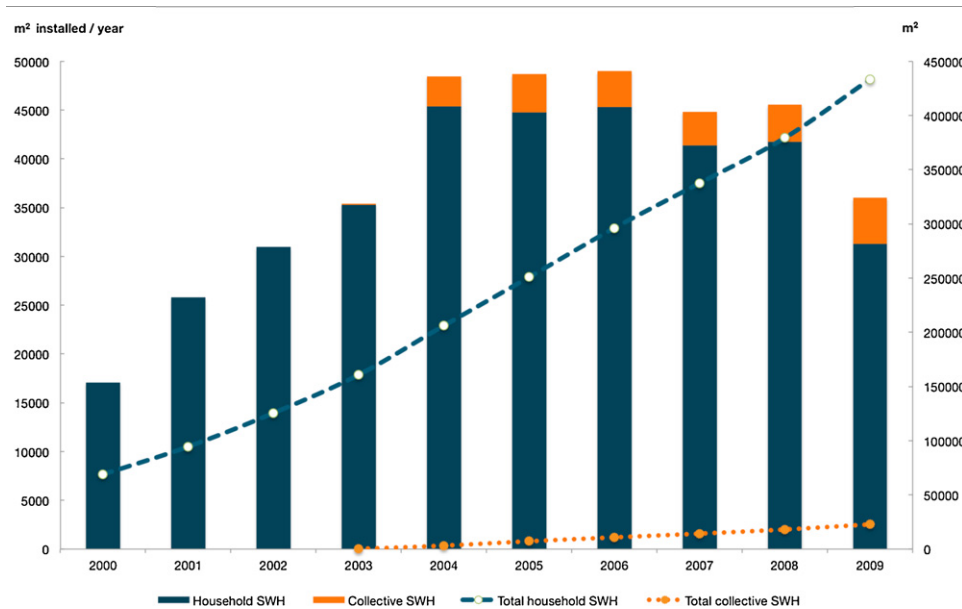


Fig. 4. Installed solar collector area for SWH.

The typical SWH system installed for household use consists in a thermosyphon water heater, with $2 \times 2 \text{ m}^2$ of selective flat-plate collectors and a 300 L storage tank. This type of installation allows a solar saving fraction higher than 0.8. It saves 1500 kWh of electricity per year, which corresponds to 150 €. In detached houses, the equipment rate of households with SWH reached 46%, but it remains very low in collective housing (9%). Thus, the potential development of SWH is still considerable and could significantly impact upon the drop in energy demand. It is well known that the average life cycle of SWH is about 20 years. The first SWH devices installed are currently reaching their end-of-life. Given that the flow of installations has increased over the last 10 years, this tendency will only accelerate with time. At present, no network or specific dismantling unit exists in order to proceed with the recycling of water heaters. An initial quote (without transport) estimates the cost of dismantling at 155 €, an additional cost to be met by the private individual. The professionals of solar energy are currently under no obligation to remove used SWH systems. The creation of such a network could be easily envisaged due to the grouping of the SWH sector with the D3E.² In spite of the D3E regulation, nothing has been put in place regarding the recycling and the valorization of the waste stemming from solar water heaters at the end of their lives.

Solar thermal energy offers many other possible applications, two examples of which can be found in Reunion:

- solar drying,
- solar cooling systems [17,18].

Until 2009, open sun drying was mainly practised on a small scale by farmers for many food products. The objective is to prevent deterioration over a period by reducing the moisture rate in the product. In Reunion, turmeric, lentils and vanilla pods are dried by the sun. In the case of green vanilla pods, the process of drying generally falls into three stages. For 2–6 weeks, vanilla is dried a few hours a day, first in an oven (65 °C), then in the sunlight, and finally in the shade for better quality. Solar drying did not lead to

any significant development, which is why no quantification of the electricity energy saved has been undertaken.

Wastewater sludge is also dried in a greenhouse using robots, in the form of swaths. Once the process is complete, the sludge is valued as a fertilizer in agriculture, through incineration with energy recovery, or put into landfill site ISDND.³ All wastewater treatment plants in Reunion use the activated sludge process. Since 2009, new plants have included sludge solar driers.

In 2003, the PIMENT Laboratory of the University of Reunion Island started investigation into a solar cooling project [19,20]. Currently, there are four solar air-conditioning installations in Reunion. The technology of thermally driven chillers that is most used is based on an absorption cycle because it is particularly adapted to small-scale installations, [21–23]. The solar cooling plant installed at the university is included in the IEA task 38 on solar air-conditioning and refrigeration. The installation shown in Fig. 5 cools classrooms (total: 180 m²) and is constituted of 90 m² of double glazed collectors, a 30 kW LiBr absorption chiller and a wet cooling tower, [24,25]. No back up is used in the system. This set-up is part of three consecutive ANR⁴ projects, which deal with several aspects of solar cooling such as modelling, experimentation, optimization and monitoring.

The average production of the installation is near 120 kWh/day, which corresponds to a total of 20.16 MWh of electricity saved during the summer period. Thus, the cooling plant has saved 16.5 t of CO₂ yearly. Many experiments have been carried out in France in order to guarantee the performance of future commercialized solar air-conditioning systems. The latest ANR project called MEGAPICS⁵ deals with this objective. This project will end in December 2012, and will provide a tool to help planners in designing solutions (collector area, storage tank volume, etc.) for solar air-conditioning.

3.1.2. Photovoltaics

At the end of 2010 in Reunion, PV systems represented approximately a power of 80 MW_p for an electricity production of 60 GWh,

² D3E: Electric and Electronic Equipment Waste regulation for French overseas départements, which is theoretically effective since November 15th, 2007.

³ ISDND: Storage installation of the non-hazardous waste.

⁴ ANR: French National Research Agency.

⁵ MEGAPICS: Method to guarantee the performance of air conditioning/heating solar system.



Fig. 5. Solar-air conditioning installation settled at University of Reunion Island.

[26]. Over the last 5 years, an exponential increase of the PV installations has been observed. The first PV systems set up in Reunion were stand-alone systems. Today, the economy of the island is focused on the PV farms connected to the grid. In 2009, with a ratio of 52 W_p of PV per inhabitant, Reunion was the third best-equipped territory after Spain and Germany, [27].

Due to its high relief, Reunion Island includes many places that cannot be easily connected to the electricity grid. Historically the first PV systems were set up in these isolated places in order to provide the power requirements for “modern” life and to improve their economic development, especially for tourist activities. These stand-alone PV systems were dedicated to providing electricity to residential houses. The average size is around 1 kW_p per installation.

The first stand-alone system was set up in the early 1980s, but these isolated sites began to be provided with stand-alone systems only after 1995. At this date, the local councils initiated an incentive policy based on financial aid. In 2009, 649 kW_p of stand-alone PV systems were set up on 650 residential houses. The majority of isolated places were equipped and there has been no significant increase of these systems between 2006 and the present date, [27]. Most of these small installations are between 5 and 15 years old and they are supplied with well-known technologies: crystalline silicon solar cells and lead batteries.

All the grid connected PV farms are situated in the coastal part of the island due to its high solar potential (see map of the geographical situation of the grid connected systems, [26], in Fig. 6). This type of system is composed of two main categories. The first category concerns small PV arrays, with a peak power lower than 36 kVA, representing 90% of systems installed but only 10% of the total installed power. These small PV farms are set up on the roofs of residential houses. They are supplied with crystalline silicon solar cells. The mono-crystalline technology is well adapted to small areas like roofs in order to maximize power, while the poly-crystalline technology offers good value between price and peak power. The second category concerns the large PV farms with a minimal power of 1000 kVA. At the end of 2009, they represented 57% of the total installed power and yet there are only 8 PV farms for a total of 629 installed systems, [27]. They are set up on large industrial roofs with polycrystalline solar cells or directly on the ground, also with polycrystalline solar cells or with thin film solar cells.

In 2002, the French government initiated an incentive policy for the development of grid connected PV with a sale cost of PV production of 0.305 €. In 2006, the sale price increased in French overseas territories to reach 0.55 € (5 times the price of electricity in France)

for building integrated PV (BIPV). Cumulated with tax reduction and financial aids, the payback time of the grid-connected systems was reduced to approximately 6 years. Since 2006, the effect of this incentive policy has been an exponential increase of the grid-connected system in Reunion (see Fig. 7).

Facing this substantial development of PV and the increasing cost of purchasing PV energy, the French government decided in 2010 to bring down the sale cost. A first drop was decided in the beginning of the year 2010 for the BIPV and from the end of 2010 onwards, a linear decrease of all sale prices was observed as shown in Fig. 8.

3.2. Wind energy

Nearly all year long, trade winds blow on the coastal part of Reunion. Due to the direction of the trade wind and the high relief of the island, a phenomenon of wind acceleration is observed on the southeast and northeast littoral. These two areas are suitable for wind power generation because more than 60% of the year the wind blows with a wind speed up to 4 m/s, mainly during the dry season between April and November, [13].

Currently only two wind farms are set up in Reunion. The first one, situated on the northeast coast, has a power of 8.4 MW. The second is situated in the southeast part of the island and has a power of 6.3 MW. They have been working since 2006. In 2009 these two farms produced 15.5 MWh of electricity, [27].

During the wet season, the island is exposed to violent hurricanes with wind speeds that can exceed 200 km/h. At such speed, no wind turbine technologies are able to stand without sustaining irreversible damage. Special pull-down wind turbine technology was implemented in the two Reunion wind farms. In the case of hurricanes, they are pulled down manually, [28]. These wind turbines have a limited nominal power of 275 kW in order to have a weight compatible with the pull-down function.

The potential of wind power generation was estimated at 60 MW for the island, [29]. New projects of wind farms are expected to achieve this goal, but it is not sufficient. More powerful generators that can stand up to hurricane conditions must be set up so as to increase the power density of the farms.

3.3. Hydropower

The production of electricity from water power is the main renewable resource of the island. Being the first renewable energy used in Reunion Island, it provided 100% of the production required

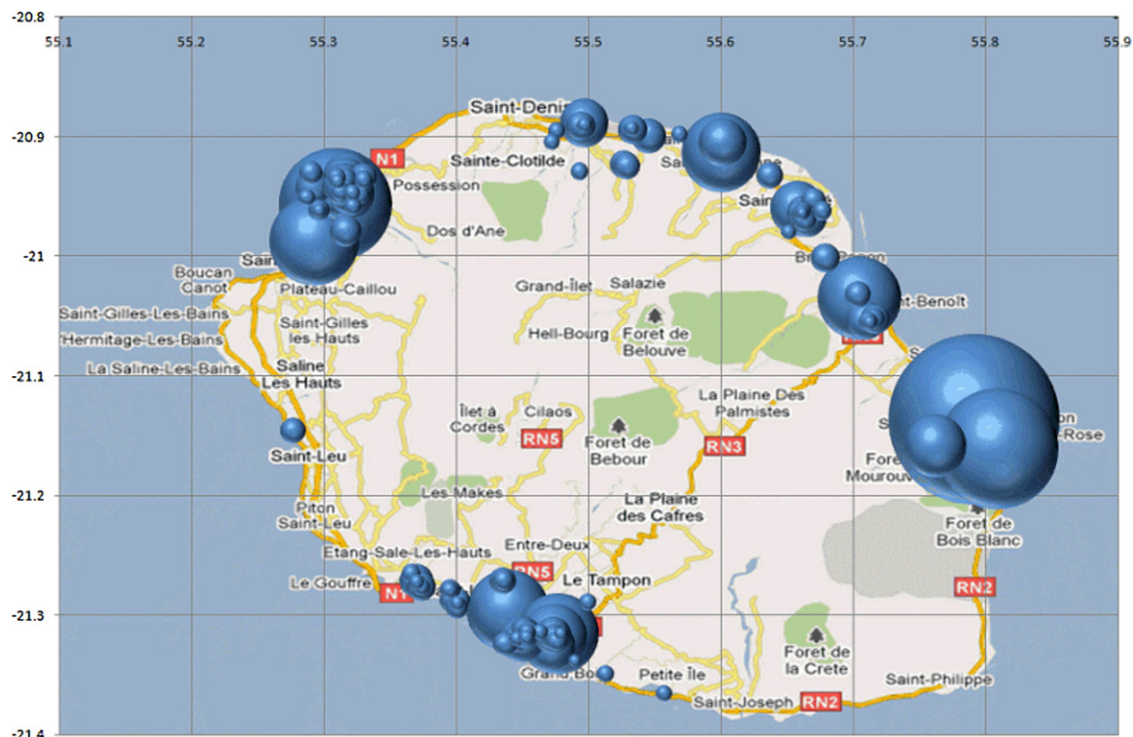


Fig. 6. Grid-connected system in Reunion.

in 1982, but in 2008 it only accounted for a quarter of the total production of the island, with a production of 632 GWh for an installed capacity of 121 MW spread over 6 sites on the island [27]. Due to relief constraints, the water storage provided by these 6 dams is relatively small. The generation of hydropower can be considered as an online electricity production and production varies from year to year according to rainfall.

3.4. Biomass

Reunion's biomass is varied and prolific and it offers a considerable potential source of energy. Technologies of transformation

energy are currently applied to agriculture and the forest sectors, at the community, industrial and individual levels. The bagasse resulting from an industrial process is already of interest for energy production. Indeed, sugar cane residues are entirely energy-valued in the two bagasse-coal thermal power plants of "Bois rouge" and "Le Gol" with a total of power 108 MW in 2005.

Thanks to a cogenerated process, its combustion also makes it possible to provide heat, in the form of vapour, in the sugar factories. The power stations use 80% of bagasse (590,000 t in 2003) and 20% of coal during the sugar campaign, but they only work with coal from October to June. The bagasse allows the importation of coal from South Africa to be limited for 4 months. This local

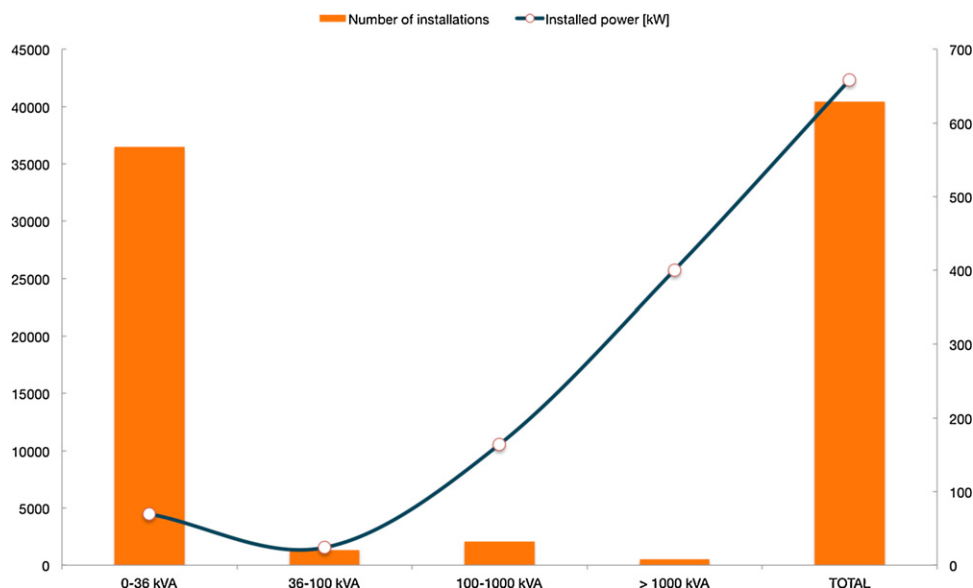


Fig. 7. Installed power and number of installations.

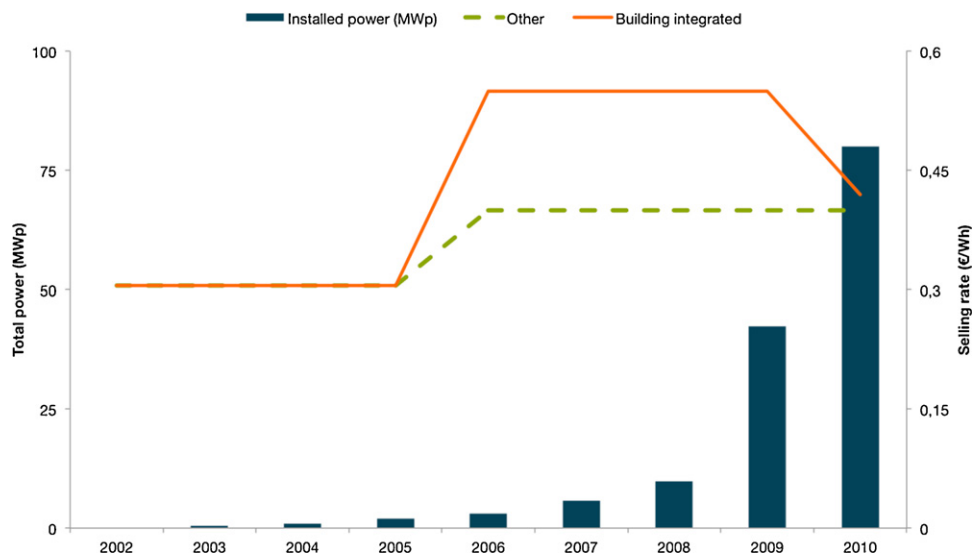


Fig. 8. Yearly evolution of installed power and sale cost.

resource, which, until a few years ago, was underdeveloped and even problematic, has become one of the major sources of energy production, just after fossil resources. Incentive-based policies in favour of the use of biomass would widely contribute to the energy independence of the island.

3.4.1. Wood energy

Tropical forest covers a total surface of 1000 km² in Reunion, 40% of which is managed by the ONF.⁶ This rich and varied biotope is protected to avoid any introduction of external plants and thus to preserve its diversity. The utilization of the forest for construction is constant, according to data taken from Jaako Poyry's study, [30]. The exploited volumes are as follows:

- 6000 m³/year of cryptomeria.
- 750 m³/year of tamarind.

The future opening of a new sawmill will increase the exploited volumes:

- 10,000 m³/year of cryptomeria tree,
- 1000 m³/year of tamarind tree.

Mearnsii Acacia, an invasive vegetal species, is a resource that has strongly developed and currently covers between 5000 and 6000 ha. Primarily situated in the heights of the West (the Plug) and the heights of the South, the extension of these surfaces reaches about 5% per annum (250 ha/year) according to the Forest Regional Orientation (FOR). While being based on an operating cycle of 3000 hectares, over a duration of 10 years, and a biological production of 20 m³/ha/year, the layer that is likely to be mobilized would be of 60,000 t/year. This is but one of the potentially exploitable options that merits refining.

3.4.2. Green waste

The green waste taken into account is the waste that results from the maintenance of public or private green spaces and collection by private individuals. Green waste represents 73,740 t, of which 57,000 t are collected door-to-door while private companies produce 7129 t per year.

The Reunion and European SAVE⁷ programme defined an action plan in 2005 in favour of wood-energy development, [31]. The regional agency of ADEME⁸ has studied the feasibility of the project. A budget of 10 k€ was released.

3.4.3. Fermentable fraction of household refuse

The total volume of household refuse is evaluated at 291 kg hab⁻¹ year⁻¹ [32]. The putrescible share, which may be valuable through digestion, is estimated at nearly 104 kg hab⁻¹ year⁻¹. In 2011, household waste represents 86,580 t and this value will rise to 91,614 t in 2025.

According to the guide of digestion of waste published by the ADEME: "Methanization" [33] the mixture of methane and green waste is evaluated at 55 Nm³ methane per ton of waste entering the digester. A gas engine with an electrical efficiency of 35% and a thermal efficiency of 50% was used to value the produced methane.

3.4.4. Industrial effluents

The companies and industries generating the biggest amount of waste of organic nature belong to the food-processing sector. The valorization of the waste produced by these agribusiness industries is still undeveloped. Waste deriving from sugar refineries is of major importance. Bagasse, scum and molasses respectively account for 588,024, 99,815 and 62,300 t in 2000 (cf. Table 4). Bagasse is used as fuel in the thermal plants of the sugar refineries.

The first experimental pilot was built in 1987, in a farm located in the highlands. The plant allowed the farm to be independent in electricity. The installation was stopped in 1994, [35]. Currently, a methanisor is being installed at the rum distillery of Beaufonds to produce biogas from the residuary liquor. Recovered heat will serve in the various processes of the distillation of rum.

3.4.5. Agricultural waste

The effluents of breeding represent the major part of organic materials of agriculture; for 2011, this corresponds to two million tons of brut matter. The total quantity of the breeding effluents was 623,500 t in 2000 [35]. Almost all the waste production comes from bovine, porcine and poultry sources.

⁶ ONF: National Forest Agency.

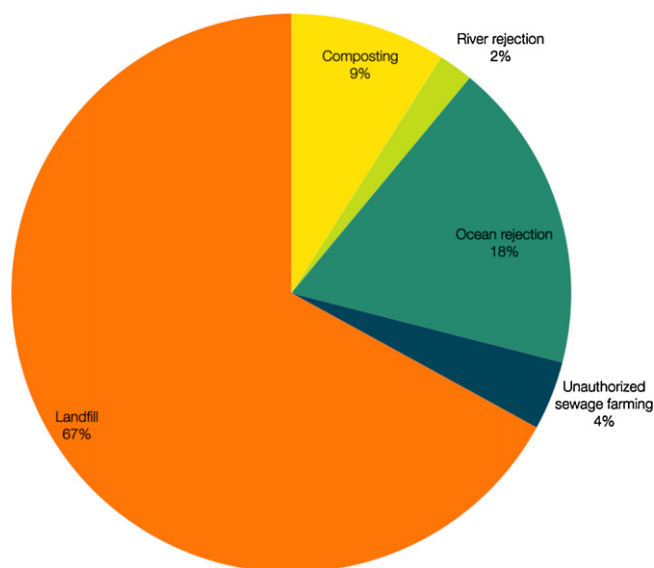
⁷ SAVE: Energy Saving.

⁸ ADEME: French Environment and Energy Management Agency.

Table 4

Synthesis of the biogas production from the industrial effluents [34].

Industrial organic waste	Total quantity (t)	Production of methane (thousands of Nm ³)	Energy (MWh/an)	Co generated energy (MWh/an)	Production electricity maximal (MWh/an)	Total energy (GWh)	Total electricity (Tep)
Vinasse	127,512	31,305	197,275	123,297	81,376	204	6998
Scums	99,815	4183	26,365	16,478	10,875	27	935
Muck	62,300	17,496	110,255	68,909	45,480	114	3911
Waste of the cereal processes	22,733	680	4289	2680	1769	4	152
Water containing sodium	5400	0	0	0	0	0	0
Industrial waste of the meat	7000	272	1716	1073	708	1	60
Compost of meat waste	1000	23	150	94	62	0.16	5
Ashes of bagasse	36,000	0	0	0	0	0	0
Refusal of manufacture various	2500	67	424	265	175	0	15
Total of industrial waste	385,960	55,069	347,029	216,893	143,149	360	12,311

**Fig. 9.** Current valorization of sludge from wastewater treatment plant [36].

3.4.6. Sludge of the treatment plants

Reunion counts 14 wastewater treatment plants treating nearly 380,000 PE.⁹ These plants generate sludge, the valuation of which remains problematic (see Fig. 9). Indeed, it is either put in landfills, spread without authorization or expelled into gullies and the ocean. This situation will become decisive, as ten new plants will be constructed in the next 15 years.

In the future, the solutions for sludge valuation would be composed of thermal drying to reach dryness higher than 30% in combination with a process of anaerobic digestion [37,38].

Wastewater treatment plants represent a nominal capacity of 296,000 PE in 2011 and will represent 755,000 PE in 2020 [39]. At present, the maximal production of electricity is estimated at 938 MWh/year and will reach 3886 MWh/year in 2020.

3.4.7. Landfill gas power plant

There are two landfill plants in Reunion. At the end of 2004, the landfill site of Sainte Suzanne stocked 1.24 million t of hidden waste. The saturation level of the site is projected for 2013, with 600,000 t of additional waste. According to current analyses, the gases collected would contain less than 30% of methane and produce nearly 1200 Nm³/h. According to initial projections for the

exploitation of biogas, the layer would be active over more than 15 years and 47 million Nm³ of methane would be developed by 2020.

3500 m³ of biogas would be valuable over 15 years, representing nearly 184 million Nm³ of methane.

3.4.8. Biofuels

Concerning biodiesel, the production of sunflowers or other oleaginous plants is generally carried out on small and dispersed surfaces. The remaining resources being very modest, a biodiesel field cannot be installed. Biofuel production from sugarcane is competing with sugar production. Moreover, workable areas are reduced, which is why this sector is currently at a standstill. Table 5 sums up the value of every production according to the different waste resource.

Using biofuel as an alternative to diesel is a hard choice but countries such as Brazil, for example, want to invest in this way [40].

4. Current energy policies

4.1. Energy plan

Since the end of the 1990s, Reunion has known a boom in investment in renewable energy. This deployment is mainly due to the incentives put in place by regional energy policy. To encourage people to use RES, the Regional Council of Reunion drafted and approved the PRERURE¹⁰ plan in 2000, [42]. This energy plan was the precursor of a national programme for Reunion, GERRI¹¹ in 2008, [43]. The PRERURE establishes a programme of investment and development to achieve 100% renewable energy (see Fig. 10). These objectives will be achieved through the use of several methods such as reducing reliance on fossil fuels, promoting renewable industry and providing financial aid. Three incentive mechanisms are currently implemented: tax exemptions, direct subsidies and advantageous feed-in tariffs (FIT) by EDF.¹² The GERRI project is directly in line with the targets set by the roadmap fixed by the “Grenelle de l’Environnement”.

The Regional Council of Reunion firstly implemented a SWH programme to accelerate the deployment of the latter. Since 2005, a tax credit has been created. This tax covers 50% of the material cost, which is of 1600 € for a traditional SWH installation of 4 m² of solar collectors and a 300 L storage tank. CSTB¹³ or any European

¹⁰ PRERURE: Regional Plan for Renewable Energies and Rational Use of Energy.

¹¹ GERRI: Green Energy Revolution Reunion Island.

¹² EDF: French electricity provider.

¹³ CSTB: Scientific and Technical Centre for Building.

⁹ PE: Population Equivalent.

Table 5
Production of biogas and electricity from the organic matter, [36,39,41].

Resources	Total matter (t)	Production of methane (thousands of Nm ³)	Energy (MWh/an)	Cogenerated energy (MWh/an)	Total electricity (MWh/an)
Green waste	57,000	2050	12,900	8065	5325
Industrials waste	385,960	55,069	347,029	216,893	143,149
Agricultural waste	1,976,243	414,450	2,598,583	1,624,114	1,071,915
Sludge of waste water treatment	7148	380	2396	1497	988
Fermentable fraction of the household refuse	80,465	4426	30,067	18,792	12,403
Landfills	1,838,554	15,410	116,530	72,832	48,069
Biogas produced	2,506,816	491,785	3,107,505	1,942,193	1,281,849

institute must certify the SWH system in order for the tax credit to be obtained.

Concerning PV, its development has been partly curbed by a new decree by the French government. The photovoltaic sector represents 70 companies and nearly 600 jobs created for a fleet of 500 MW, against 81 in 2008. On August 2010, a first decree decreased financial aid by 12% for installations producing more than 3 kW_p, [44]. On 5th March 2011, a second decrease of 20% was implemented, [45]. These decrees particularly disadvantage large-scale installations. Table 6 sums up the main tariffs currently applied since March 2011. Before the new decree framework, a PV system could cost 15,000 € per private individual, now its price has risen to approximately 25,000 €. Thus where 100% return on investment was initially obtained at the end of 8–10 years, now this will in all likelihood take 15 years. Moreover, PV production must not reach 30% as defined by EDF. This limit of market penetration is fixed in order to guarantee the stability of the electricity network. All these measures will mean a significant reduction of the PV market in Reunion in 2011. The solar sector is currently the most developed. FIT has also been defined for the other renewable energy sources, even if their deployment is less considerable in the energy mix. Electricity from wind energy has a FIT of 0.11 and 0.13 €/kWh for offshore plants. Production from biogas is valued

up to 0.7798 €/kWh (>2 MW) or 0.9359 €/kWh (≤150 kW). Two subsidies could be added, the first with 0.208 €/kWh is for methanization. The second concerns energy efficiency: for a range value of 40–75%, the subsidy could reach 0.3119 €/kWh. On August 1st, 2010, Reunion was added to the UNESCO World heritage list, [46]. Peaks, cirques and ramparts create a spectacular landscape, which significantly contributes to the conservation of biodiversity. The tropical forest in the island's national park is also listed. Due to this situation, the solid biomass field will probably not really develop in Reunion in the coming years. On the national scale, this field raises many doubts. Two main problems lead to the cancellation of projects: the first relates to the supply of raw material sites while the second barrier concerns efficiency. The UNESCO listing has also brought geothermal energy projects to a halt. No modification for any plant in the volcano region is now possible. Due to general protest by the population and questions raised regarding the impact on air quality, the project for a waste combustion plant has also been postponed. Ocean energy and solar thermodynamic electricity are currently under experiment in France. At the end of 2009, there were, respectively, 240 MW and 10 kW power plants installed on the French territory. The objectives for 2020 are around 800 MW (sea energy) and 540 MW (solar thermodynamics). As these fields are just beginning to take shape, no real FIT or subsidies

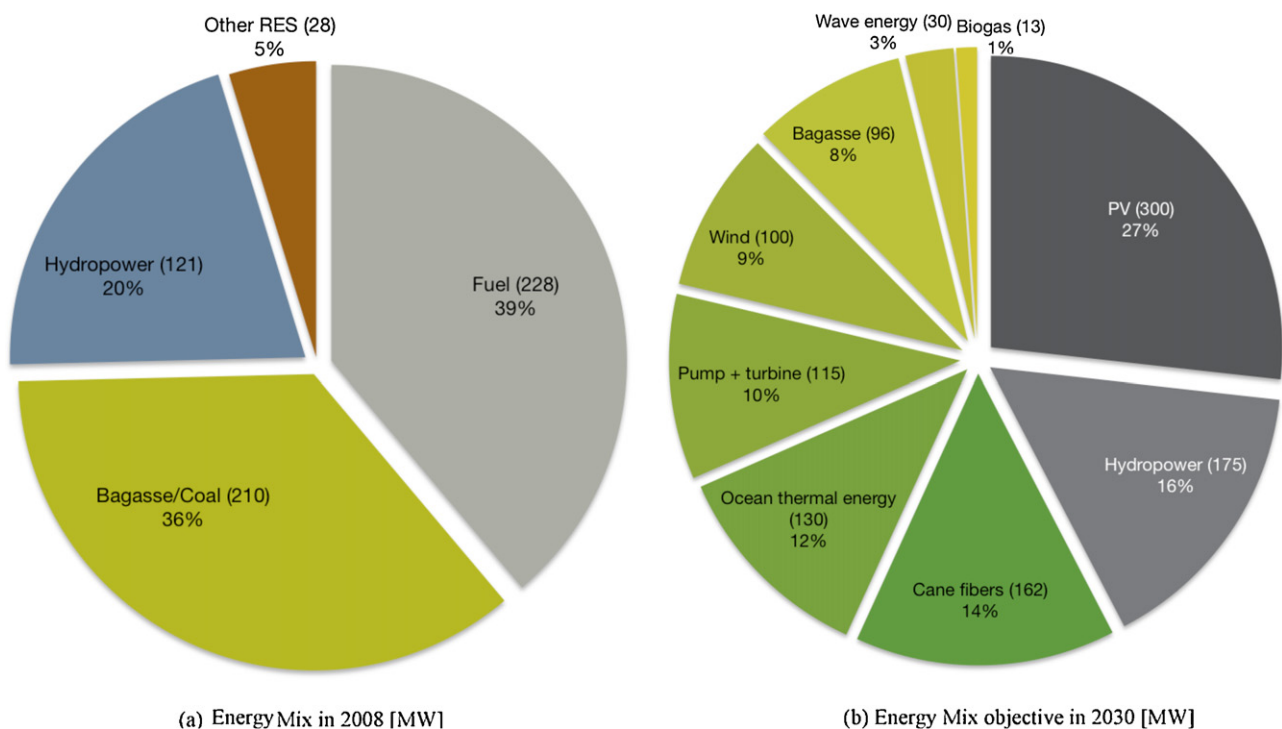


Fig. 10. Evolution of Energy mix in Reunion according to the PRERURE plan.

Table 6
Feed-in tariff for PV in 2011.

	Type of installation		Feed-in tariff in 2011
Residential house	BIPV	[0–9 kW _p]	0.46 €/kWh
		[9–36 kW _p]	0.406 €/kWh
	Simplified BIPV	[0–36 kW _p]	0.3035 €/kWh
		[36–100 kW _p]	0.2885 €/kWh
Other buildings	BIPV	[0–9 kW _p]	0.352 €/kWh
		[0–36 kW _p]	0.3035 €/kWh
	Simplified BIPV	[36–100 kW _p]	0.2885 €/kWh

are currently in place. Nonetheless, despite the relative youth of these new technology fields, some significant gains can still be expected in terms of electricity consumption. The LOOM¹⁴ is the law providing for greater decentralisation towards French overseas *départements*, [47]. This law makes it possible for the Regional Council to formulate an independent programme for energy-side management and renewable energy. It seems necessary that the action of the *département* and the districts is consistent with the PRERURE. On the one hand, the programme must be applied on a territorial scale. On the other hand, individual communities have to take part in the decision-making process pertaining to this energy plan. The GERRI project energy carried by the French state sets the targets for energy self-sufficiency at 100% for electricity in 2025 (as expected by the PRERURE) and transport in 2030. Currently, this project seems to be in a lag phase. The most considerable impact on renewable energy development has been due to the application of the PRERURE. Three areas are significant: renewable energy technologies, energy-side management and the creation of an energy observatory, tracking the evolution of Reunion's self-sufficiency (RES deployment, economic impact, etc.) and implementing scenarios of energy analysis.

The European Union plays a vital role in financing energy policy. Many support mechanisms are available in the EU. This support is distributed in two ways:

- Directly, EU supports a development or research project by funding it in part or in full. Via calls for tenders, the EU directly helps project managers.
- Indirectly, by providing support to regional authorities in order to enable them to apply European policy.

Concerning private renewable plants, a tax credit exists on the purchase of materials. The rate varies from 25% to 50% depending on conditions and the technology in question.

In the research field, the European Research Council (ERC) has encouraged “brain circulation” since 2007 by investing in exchange programmes and cooperation between research laboratories within the EU. The FP7 has widely supported large-scale European projects. Researchers from the University of Reunion Island are participating more and more in the different FP7 programmes. With a view to achieving the objective of sustainable growth, another EU tool is the Intelligent Energy Program (IEE) which supports projects aiming at eliminating non-technical barriers (political, socio-economic, market, ...) through training schemes and education, transfer of skills, promotion of best practices, creation of harmonized standards or practices and dissemination of information. The GEOFAR¹⁵ Project, which deals with promoting geothermal energy in Europe, ended on February 2011. Reunion was included in this project due to its high potential,

however the geothermal project was not retained finally due to the location of the future plant.

4.2. Thermal standards, net zero buildings

The energy demand of buildings represents more than 30% of the total energy consumption of Reunion, including transport. Its reduction is one of the main goals to achieve in order to attain GERRI's objectives. First, two experimental eco-labels based on the bioclimatic concept were developed. They were used as a preliminary study for the elaboration of thermal standards for French overseas territories. And, more recently, experimental net zero energy constructions have been built.

ECODOM, the first eco-label for Reunion's buildings, was created in 1997, [48]. It was dedicated to the construction of new dwellings in the coastal part of the French overseas islands, below 400 m of altitude. In this area, the climate is warm and humid for 4–5 months of the wet season, between December and April. The main goal of ECODOM was to avoid the unconditional recourse to cooling systems during these months. It is based on the improvement of roof insulation, solar shades and natural cross ventilation. In 2004, a second eco-label, PERENE (acronym of Energy Performance of Buildings), was established. It was updated in 2009, [49]. It deals with all the different climates of the island, from the coast to the altitude areas, and a larger range of constructions: residential, commercial, office, educational and health buildings. In 2004, the lack of local energy and thermal codes implied that most buildings were not adapted to the climate and were energy non-efficient, uncomfortable and non-healthy. To mitigate the growing energy demand of the building sector, the local representative of the French ministry of Building and Housing – DDE¹⁶ decided to launch the PERENE project. The main objective was to produce a document based on experience and local skills gained throughout the last 15 years in the residential and non-residential sector. Former experimental standards like ECODOM, green building experimental projects and the realization of more than 45 energy diagnoses conducted in tertiary buildings (see Table 7) were investigated in producing the document.

The first thermal standards (RTAA DOM) have only been implemented for new dwellings since the 1st May 2010, [16]. While they mainly use the same factors as the PERENE eco-label, the overall requirements are less restrictive. They are defined in three articles that give the rules for:

- The thermal properties of walls and windows,
- Natural cross-ventilation and air conditioning systems,
- The acoustic properties of walls, windows and systems.

These thermal standards are recent and as yet no results are available regarding their impact on the energy consumption of the buildings concerned.

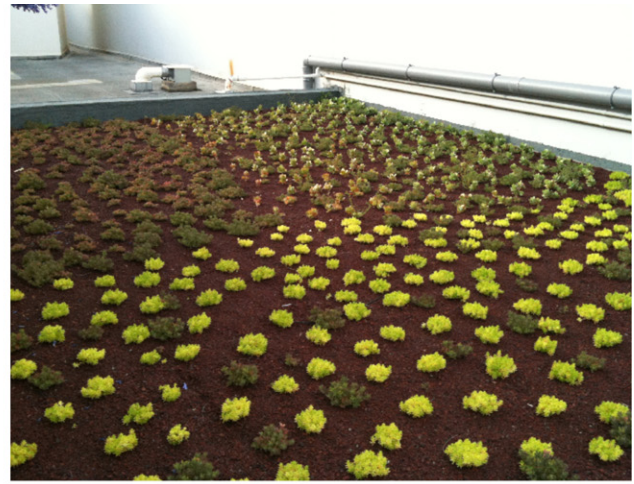
¹⁴ LOOM: Overseas Territories Orientation Law, December 13th, 2000.

¹⁵ GEOFAR: Geothermal Finance and Awareness in European Regions.

¹⁶ DDE: Departmental office of infrastructure.



(a) ENERPOS : A net zero energy building



(b) First green roof experiment at the University

Fig. 11. Building experiment at PIMENT Laboratory – Civil Engineering Department.

The high solar potential and the clement weather of Reunion Island are well adapted for the construction of buildings that produce more energy than they consume. The first zero energy building of the French overseas *départements* is located in Reunion Island. It is a building of the University of Reunion with around 800 m² of classrooms and offices. The design and the construction of that building perfectly matched the achievements of the ENERPOS project [50,51]. It was completed in October 2008. The ENERPOS building, named after the project itself, is a very low energy building (cf. Fig. 11). The main features are listed below: all rooms and spaces are cross naturally ventilated and equipped with high efficient ceiling fans. The tutorial classrooms have no air-conditioning at all. Solar shadings have been designed and optimized thanks to 3D simulations. The building meets the PERENE requirements. 350 m² of BIPV roofs (50 kW_p) produce the renewable energy of the building. With this first experiment the local University is involved in the IEA task 40 about Net Zero Energy Solar Buildings.

The reduction in the energy consumption of a building must include new passive solutions to refresh the air, such as green roofs. This solution is currently used in Europe but very little in the southern hemisphere. However, extensive investigations are being carried out at the University regarding green roofs. The first stage of this study consisted in setting up and monitoring an experimental roof in order to obtain a database (see Fig. 11). The modelling and simulation stages are currently in progress [52,53].

Table 7
Annual electricity demand of buildings in Reunion (2009).

	Ratio of annual electricity consumption (kWh _{elec} /m ²)	
	Actual	PERENE
Individual house	36	25
Flat	44	28
Office (small building)	140	65
Office (large building)	140	70
Primary school	22	11
High school	36	18
University	140	70
Hospital (living area)	160	100
Hospital (healthy area)	250	200
Hotel (2–4 stars)	182	160
Shop	350	315
Shopping mall	580	465

5. Perspectives for deployment of other RES technologies

Solar thermal and photovoltaic products have boomed since 2000 in Reunion's renewable energy market. The road map for RES identifies several other technologies in order to take up demonstration activities and research development. The final aim is to increase the share of RES in Reunion's energy mix. Furthermore, the use of non-intermittent RES will help to stabilize energy supply.

5.1. Sea energy

The use of marine energies in the energy mix of the island has been studied since 2005. Research projects and experiments are being developed. The first projects will be almost ready to launch by the end of 2011 (see Fig. 12).

5.1.1. Ocean thermal energy conversion – sea water air conditioning

Ocean Thermal Energy Conversion (OTEC) allows the production of electricity using cold water from the deep seawater (1000 m and 5 °C) and surface water (between 25 and 28 °C) as hot spring. With this small temperature gradient, the production of electricity is made possible using a Rankine cycle. Currently, experimental power plants are working on that subject and in the last year many studies have been initiated [54]. In 2005, Reunion began to study the integration of OTEC into the energy blueprint for the island. Feasibility studies have been carried out [55] and research projects are in progress [56]. They concern the future installation of a 10 MW offshore demonstration power plant in 2014. An experimental system will also be set up in 2011 and will assess the efficiency of the future demonstrator [57]. The island has several prospective sites. Sainte Rose is a world-class site in terms of difference in depth: 1 km deep at 2 km off the coast, [58]. The portion of OTEC should provide 130 MW in the energy blueprint by 2030.

Like OTEC, SWAC uses the deep water for cooling buildings in a city or in an urban network of air conditioning. Projects already exist such as in Bora Bora, [59] or are under study such as in Honolulu [60]. A project is under consideration in Reunion, [61]. It will be dedicated to the cooling of the airport offices as well as the university offices, located in the towns of Sainte Marie and Saint Denis, in the north of the island. The installed cooling capacity will be 40 MW, [57].

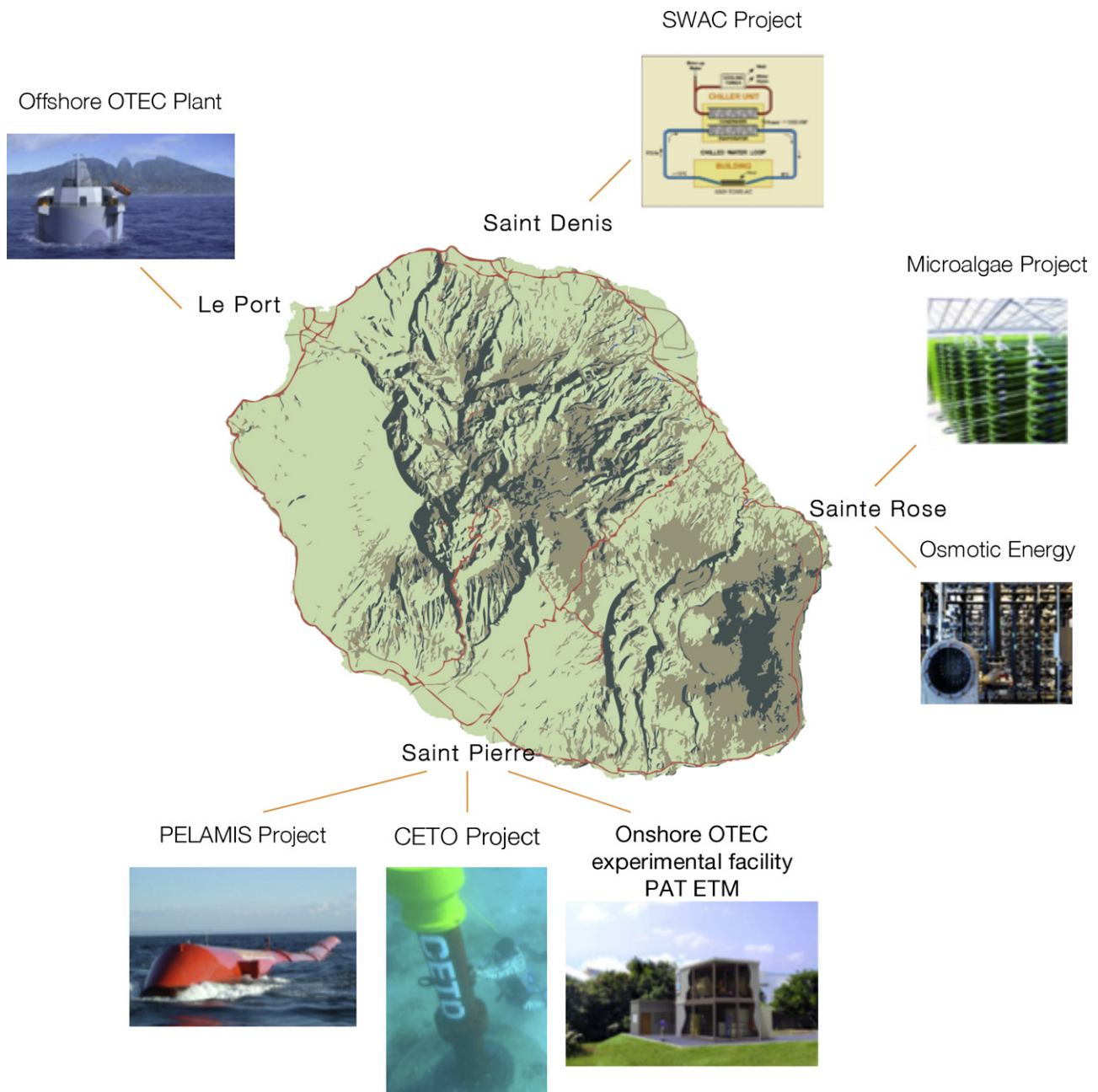


Fig. 12. Future experimental projects in sea energy.

5.1.2. Wave energy

The use of waves can generate electricity by converting the power of the swell. Two technologies are considered for the island: Pelamis Technology, from Scotland, and CETO Technology, from Australia.

In Reunion, the Seawatt project will use Pelamis. With a good level of investment, this project could provide up to 10% of the island's energy requirements.

A pilot plant, consisting in 3–5 modules of 1 MW, is scheduled for 2012 and will be connected to the grid. The implantation site selected is located 2 km off the coast of Saint Pierre in the south of the island, [62].

The principle of the second technology (CETO) can be explained as follows: a float moved by the wave transmits its movement to a pump that provides a pressurized fluid. This fluid feeds an onshore turbine to generate electricity, [63].

A real-scale pilot will be set up to study the behaviour of the CETO in the swell conditions of Reunion. In a second phase, a 2 MW power plant will be connected to the grid. Pelamis, the CETO project, will be installed off the coast of St. Pierre [57].

5.1.3. Microalgae

The use of algae could be integrated in the energy mix. Several fields are being explored, [64]. The main possibilities are:

- Bio fuel production.
- Wastewater treatment and anaerobic digestion.

In addition, the use of deep cold water (OTEC), rich in nutrients, allows the production of microalgae by minimizing the use of fertilizers. In Hawaii, this process adds value to the cold-water resource [65].

5.1.4. Osmotic energy

The osmotic process uses the phenomenon of osmosis. It consists in a flow between highly and weakly salt-concentrated waters, using a semi permeable membrane. This principle can be used to produce electricity by applying it to freshwater and seawater under pressure [66].

A project is under consideration in the town of Sainte Rose by exploiting the freshwater disposal of a hydroelectric plant [67].

5.2. Biomass

According to PRERURE, the goals in terms of biomass energy are far from being achieved. They are divided across three fields of valorization: wood energy, digestion and gasification.

5.2.1. Wood energy

The sawmills and wood industries located on the littoral region should promote offcuts by producing particle boards or pallets. They can also burn these residuals in industrial plants to produce energy. As the available resource per unit is weak, a geographical grouping of the industries would be necessary [39].

A second possibility for valorization could be domestic heating in the highlands, at up to 600 m of altitude.

5.2.2. Biogas

The resource is sufficient; it is more economic to energetically promote biogas than to burn it in a flare tower. The return on investment occurs at around 3–5 years and the costs of maintenance and production remain weak. The main way to promote biogas is through electricity production. The lack of local outlets currently limits the thermal valorization of biogas.

Concerning the digestion of sludge from wastewater treatment plants, the strategy is the same as with biogas. Concerning the possible solutions, they remain at an experimental level. The efficiency of a large-scale biogas system is currently not proved, [68]. Research is currently being carried out to evaluate the feasibility of an industrial scale development. Possible solutions could be composting associated with digestion, nitrification and denitrification associated with digestion, and co-digestion with several wastes [69].

5.2.3. Gasification

This is a process that would make it possible to promote both agriculture and forest residues, but also the residues of digestion. The objective is to produce electricity and heat. The process allows a level of electricity production to be obtained that is almost 25% greater than that of a traditional boiler. Current studies are investigating this process by using biomass as a combustible, [70]. Local developments are looking towards other possible combustibles.

5.3. Solar thermodynamic conversion

Concentrating solar thermal technology has been widely investigated through both experiments and modelling [71–74]. Thermodynamic solar energy conversion is generally based on the Dish/Stirling system [75]. A dish collector absorbs the solar thermal energy and concentrates the sun's rays on the Stirling engine. This generator is at the focal point. In 2011, experiments have been initiated within the industry in order to study the production potential of parabolic dishes. The system installed in June 2004 at the CNRS-PROMES in France reached an overall efficiency of 22.5%, [76]. As the dish tracks the sunlight, it offers the highest optical efficiency (more than 70%). Compared to solar towers, this technology is more interesting for Reunion because of the lack of large land spaces. The current project is part of a French call for tender on solar thermodynamics. The first part of the study aims at defining potential

areas where plants could be installed; it then aims at evaluating the production potential.

5.3.1. Scenarios

EDF have provided projections of electricity demand in Reunion until 2025 [77]. Four scenarios are investigated, based on two elements (see Fig. 13). Due to the demographic slowdown and the short-term retrofitting equipment rates, the rate of growth of electricity consumption should continue to decline. Four basic scenarios for electricity demand are proposed: low, medium, high and energy-side management enhanced (ESME).

The scenarios take into account two major projects in Reunion. The first one concerns the water transfer from the east to the west region. The system consists in a series of underground pipes. The east coast receives 3000–3500 mm of rain water per year, while the west coast receives less than 1000 at sea level. The use of hydraulic pumps leads to an additional electricity power demand of 4 MW. The second project, which has finally been abandoned due to lack of funding, was a tram network between the west and the north region. The demand on electricity was expected to be 3 MW. This project was a measure taken to reduce car traffic. The last scenario (ESME) is based on a medium scenario with incentive-based energy-side management. This perspective is conceivable on condition that additional incentive actions are introduced. Several promising measures are being applied to this end, such as the RTAA DOM application and the progressive removal of incandescent lamps from the market since September 2009. This scenario will allow 18% of electricity to be saved in 2025 in either the residential or tertiary/industry sector.

6. Barriers to renewable energy development

Several barriers have been discussed in literature in order to identify the difficulties encountered by RETs to penetrate the energy market, [78–82]. These difficulties are generally specific to technology, but they could also concern political or technical aspects, cost-effectiveness, or social and environmental barriers. The identification of these barriers and the potential solutions to overcome them have been discussed in detail, [83]. Owing to the island's insularity, the cost of technologies appears as a major disadvantage in the penetration of RET. The cost of transport and local taxes could increase the cost of RETs by up to 30%, which represents a trade barrier. Thus a higher initial capital injection is necessary to install a RES system. This investment sometimes appears to be a financial risk for contractors. For example in the case of photovoltaics, the decrease of FIT has widely increased return time on investment, which penalizes the development of solar PV farms. Recent French government policy may reduce the market size of PV due to the lack of incentive access to credit for consumers. A high payback period will significantly affect the economic viability of the project.

The environment presents specific obstacles for the deployment of RETs. As it is a tropical region, the island is particularly exposed to devastating climate conditions. Each year Reunion suffers from several cyclones or extremely heavy rainfall that produces massive landslides. This is a significant risk to wind power installations for example. Moreover, its mountainous relief and volcano activity limit the available space for human activities (only one third of the territory). Demographic growth is increasing this pressure on land and adding further RET installations will further exacerbate this situation. A land development project is necessary to define administrative rules on the territory and set the guidelines to reach territorial cohesion. As Reunion is listed on the UNESCO World heritage list, new constraints appear in terms of the assessment of environmental impact. Indeed, the cost per square meter of

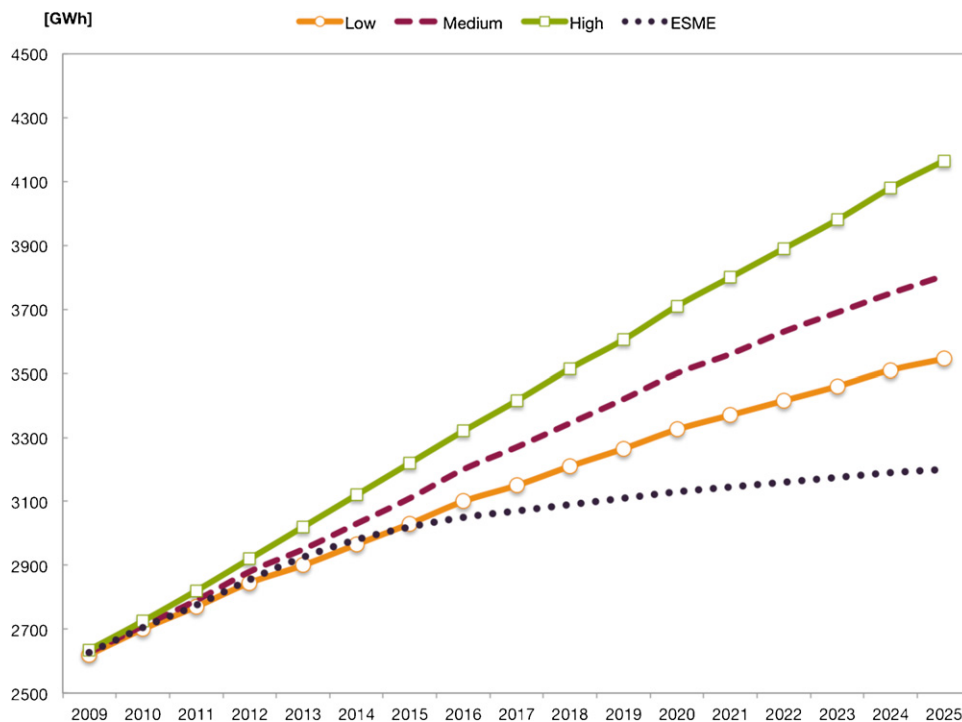


Fig. 13. Future trends of electricity consumption.

constructible ground clearly exploded in the last 10 years, leaving very few free spaces for the completion of projects.

High quality information on support measures, Reunion energy situation and RETs is not easily available to consumers. Many of the key players offer general information on programmes/campaigns but there is no clear coherence across the different websites, hence the contradictions caused by the different objectives endorsed by these players. Thus social acceptance of RETs by the consumer remains mostly mitigated. What is lacking is a one-energy agency, which could concentrate all useful information about RETs, as well as a real policy supporting the measures taken. Currently ARER,¹⁷ a not-for-profit association, acts as an advisor for authorities and promotes RETs through guidelines and pedagogical tools for consumers. High-risk perception in terms of noise pollution has made the population wary of wind energy installations. In fact, wind farm development in the east region of Reunion has partly ceased.

The final barrier is institutional: the lack of coordination between authorities leads to long administrative procedures, which can seem to constitute an obstacle course for the project-owner. Furthermore the lack of competent people providing administrative and technical support for projects leads to delays in processing projects. This is particularly noticeable in the implementation of projects linking RETs and energy-side management.

7. Conclusion

As currently envisaged by the World Trade Organization, globalization will increase the vulnerability of small insular economies like Reunion's. The sugar market reform is already an example of the brunt of globalisation. With a fast growing energy demand over the last two decades, Reunion Island is facing substantial challenges in reaching its objective of energy self-sufficiency for 2030. It is still heavily dependent on fossil fuel, which currently corresponds to 87.1% of the energy mix. Reunion is nevertheless an exemplary

département in terms of sustainable development (leading French *département* for installed RETs). Today Reunion is a small-scale insular economy, confronted with the effects of globalization. It has to integrate both the EU and the Indian Ocean environment. Its social context is particularly complex as 30% of the population is unemployed. Thus the deployment of any projects in the energy field has to take into account economic, technological and social aspects in order to prove sustainable.

In this context, Reunion seems to be a perfect testing ground for renewable energy solutions and energy-side management, issues that our planet will face on a far wider higher scale. As declared by the French Minister for the Environment: "The success of Reunion Island must foreshadow the success of France, Europe and the World in the fight against global warming and this necessary energy transition".

The definition of the key issues of energy self-sufficiency is based on several steps. The first of which was to obtain a projection of Reunion's situation in 2030 in order to define a road map for the goal of energy self-sufficiency. The second step was both to encourage the deployment of RETs and the energy-side management programme. Since 1998, an energy programme supported by the Regional Council has promoted the increase of the use of solar energy in water heating and electricity production. Other fields such as wind energy or biomass complete these initial RES. The paradox of Reunion's situation is that its share of renewable energy out of the total energy supplies is still minor and has decreased since 2000. This is explained by an inflation of demographic growth that is higher than the penetration rate of RETs. Thus energy-side management is necessary to significantly curb and finally slow down the dynamics of electricity growth in all sectors. This challenge is particularly crucial, as the amount of housing must increase from 280,000 dwellings in 2005 to 468,000 in 2030. The equivalent of a city of 15,000 people has to be built each year. Several RETs such as solar water heating, photovoltaics and hydropower have been successfully developed, and constitute the first step towards sustainable growth. To reach the ambition of self-sufficiency, all possibilities have to be explored. New RETs have been investigated

¹⁷ ARER: Reunion Regional Energy Agency.

in order to offer a better choice in the energy mix. The objective is also to develop technologies which are not intermittent or to test cogenerate solutions. Biomass is a major focus in full development. The thermal regulation RTAA DOM, which has been effective since 2010, has led to positive developments in the construction of new buildings. Following the solar water heaters, the Smart Grid now offers a new step towards energy independence. By coupling the photovoltaic panels with batteries, it is possible for an individual to produce the electricity he needs on his own. In this way, the price of energy no longer depends on external factors over which no control is possible. Despite this entire favourable and incentive context to RETs and energy-side management, Reunion still faces several barriers. The problem of land is very acute in Reunion Island, where population pressure is high and where urbanized areas are reduced. Furthermore, as many experts argue, the cost-competitiveness of RETs is a major barrier to purchasing a device. The effectiveness of technology and feed-in-tariff or subsidies have to partially remove some barriers. A last problem concerns the availability of quality and coherent information between the different key players involved in administrative procedures, support measures and energy strategy. The clear development of a network infrastructure in accordance with a long-term strategy has yet to be defined; this is also the case in France. R&D and technological innovation must be achieved in certain fields such as biogas, sea energy and energy storage. Despite the effects of the economic crisis and recent shifts in government policy on energy, the impulse initiated between 1998 and 2010 is still very much topical. Marching towards energy self-sufficiency does not seem to be a utopian dream, on condition that an incentive regional energy programme is clearly investigated and adopted. Reunion Island offers key benefits to act as a real-scale testing ground of RETs and energy management strategy for the future. It is a real opportunity to set the example of being a net zero energy island.

Acknowledgments

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